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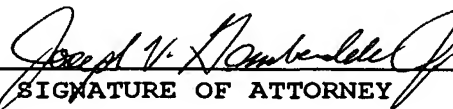
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SIGNATURE OF ATTORNEY

Reg. No.: 44,695

Joseph V. Gamberdell, Jr.

Type or print name of attorney

Tel. No.: (203) 259-1800

Perman & Green, LLPP.O. Address

Customer No.: 2512

425 Post Road,
Fairfield, CT 06824

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Agilent Technologies, Inc. - a Delaware corporation -
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WAVELENGTH DETERMINING APPARATUS AND METHOD

5 The present invention relates to an apparatus and method for determining a wavelength of electromagnetic radiation of the type emitted from a laser device, especially, though not exclusively, to such an apparatus and method for use in a wavelength locker, for example of the type that generates an error signal for controlling a wavelength of the light emitted by the laser device.

10

In a fibre-optic network, the wavelength of light used to communicate a signal is an important parameter. In particular, where Wavelength Division Multiplexing (WDM) systems are employed, different signals are communicated using respectively different wavelengths. Consequently, it is important to maintain the different wavelengths accurately in relation to components of the WDM system, for example multiplexers and demultiplexers, which add or remove wavelengths from the WDM system.

20 Typically, a semiconductor laser device is employed in a transmitter unit of the fibre-optic network. The wavelength of light transmitted by the laser device can be accurately controlled by altering a parameter, for example temperature, of the laser device using a closed loop feedback circuit. In this example, in order to determine whether to heat or cool the laser device, and to what extent, to lock the wavelength of the laser device to a predetermined wavelength, an error signal needs to be generated in the feedback circuit.

Known apparatus for detecting changes in the wavelength of the laser device are disclosed in US 4, 309, 671, US 6, 144, 025, US 5, 825, 792. US 4, 309, 671 discloses a laser diode, a proximal beam splitting mirror and a proximal photodiode to receive light from the proximal beam splitting mirror, a distal beam splitting mirror and a distal photodiode to receive light

from the distal beam splitting mirror, and a filter is disposed between the distal beam splitting mirror and the distal photodiode. An electronic control circuit is also disclosed for stabilising the laser diode. When in use, a divergent beam is emitted by the laser diode. The proximal beam splitting mirror directs a proportion of the light incident upon the proximal beam splitting mirror onto the proximal photodiode. Similarly, light passing through the proximal beam splitting mirror is incident upon the distal beam splitting mirror, the distal beam splitting mirror directing a proportion of the light incident upon the distal beam splitting mirror onto the distal photodiode. The filter has a positive transmission gradient versus wavelength characteristic, so that the light passing through it is selectively attenuated depending on its wavelength. The two photodiodes are coupled to an amplifier whereby their ratio can be utilised as a measurement of the wavelength of the light emitted by the laser, and variations in that ratio (indicative of a variation in wavelength of emitted light) are used in feedback loop to control the laser diode. Usually, since such variations in the wavelength of light emitted by the laser diode are due to variations in temperature, the feedback loop is used to adjust the temperature of the laser diode.

20

US 5, 825, 792 discloses an apparatus comprising a lens, a Fabry-Perot etalon and two photodiodes, the apparatus being copackaged with a semiconductor laser in an industry standard package known as a "butterfly" package. The etalon splits light emitted by the semiconductor laser and propagates the light over multiple paths of different lengths before recombination. Respective phases are accumulated over the multiple paths, the phases accumulated being wavelength-dependent. Consequently, the result of the recombination also depends upon wavelength. Again, the two photodiodes are coupled to an amplifier whereby their ratio can be utilised as a measurement of the wavelength of the light emitted by the laser, and variations in that ratio (indicative of a variation in wavelength of emitted light) are used in feedback loop to

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control the laser diode. By using an etalon, in which light transmission is caused by interference between light paths, the transmission characteristic is cyclical. Although, therefore, the same ratio between the outputs of the photodiodes will occur at different wavelengths whose transmission levels are the same, once the correct wavelength has been found, this apparatus will maintain the laser at that wavelength in the manner described above.

The dimensions of the etalon depend upon a required resolving power, R , of the etalon; the resolving power is a measure of a minimum change of wavelength that can be detected. The resolving power, R , of the etalon is given by the following equation:

$$R = F \frac{2nd}{\lambda_o}$$

where: F is the coefficient of finesse,
 n is the refractive index of the etalon,
 d is the thickness of the etalon, and
 λ_o is the wavelength of operation.

As a practical example, in order to monitor a 100 GHz or 50 GHz channel spacing, at least one dimension of the etalon has to be approximately 1 mm or approximately 2 mm, respectively.

US 6,144,025 discloses a laser diode coupled to a first optical fibre. When in use, light emitted by the laser diode propagates through the first optical fibre, a lens, a cut filter, after which the light is incident upon a beam splitter. A first photodiode is located on a first side of the beam splitter and a second photodiode is located on a second side of the beam splitter. An optical band-pass filter is disposed in-line between the beam splitter and the first photodiode. A proportion of the light incident upon the beam splitter is directed towards the first photodiode. A first proportion of the light directed towards the first photodiode is permitted to pass through to the first photodiode and a second proportion of the light directed towards

the first photodiode is reflected by the optical band-pass filter to the second photodiode via the beam splitter. A certain proportion of the light incident upon the beam splitter via the cut filter is permitted to pass directly through the beam splitter to a lens that focuses the transmitted light into a
5 second optical fibre.

In the apparatus of US 6, 144, 025 the two photodiodes are coupled to an output ratio calculator, whose output is coupled to a wavelength controller in a feedback path to control the laser diode, in a similar manner to that
10 described above. As an alternative to the optical band-pass filter, there can be used an interference filter to change the wavelength of light transmitted by the filter to the first photodiode.

As optical communication systems become more complicated, and it
15 becomes desirable to utilise more separate wavelength channels, lasers that are not single wavelength are becoming more prevalent, since it is easier to tune them to operate at another wavelength than to replace them by another laser operating at the different wavelength. These tunable lasers often have a tunable range of approximately 30 – 40 nm.
20 Furthermore, although the ITU presently requires a spacing of at least 0.8nm between adjacent signalling channels, as demand for channels grows, it will be necessary to reduce the spacing further, so that the resolution of the wavelength detector and the laser locker will need to be higher than hitherto.

25

Accordingly, in a first aspect, the present invention, provides an apparatus for detecting a wavelength of electromagnetic radiation, the apparatus comprising a first electromagnetic radiation detector for receiving a first proportion of electromagnetic radiation that has been redirected from a
30 main electromagnetic radiation path, a second electromagnetic radiation detector for receiving a second proportion of electromagnetic radiation that has been redirected from the main electromagnetic radiation path, a third

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electromagnetic radiation detector for receiving a third proportion of electromagnetic radiation that has been redirected from the main electromagnetic radiation path, a filter arranged for filtering the second proportion of the electromagnetic radiation before it reaches the second
5 electromagnetic radiation detector, an interferometric device arranged for causing the third proportion of the electromagnetic radiation to interfere with itself before it reaches the third electromagnetic radiation detector, and processing means coupled to receive a first signal from the first electromagnetic radiation detector indicating an intensity of the first
10 proportion of the electromagnetic radiation detected by the first electromagnetic radiation detector, a second signal from the second electromagnetic radiation detector indicating an intensity of the second proportion of the electromagnetic radiation from the filter detected by the second electromagnetic radiation detector and a third signal from the third
15 electromagnetic radiation detector indicating an intensity of the third proportion of the electromagnetic radiation from the interferometric device detected by the third electromagnetic radiation detector, the processing means determining a wavelength of the electromagnetic radiation based on the ratios of the first and second signals and the first and third signals.

20

Preferably, the filter is a broadband filter.

In a preferred embodiment, the apparatus further comprises at least one electromagnetic radiation splitter arranged in a main electromagnetic
25 radiation path for redirecting at least one of the first, second and third proportions of electromagnetic radiation from the main path.

Preferably, the electromagnetic radiation splitter is arranged in the main path of the electromagnetic radiation for redirecting said first proportion of
30 the electromagnetic radiation to the first electromagnetic radiation detector and for redirecting said second proportion of the electromagnetic radiation to the filter.

In one preferred embodiment, the interferometric device comprises a block of material that can transmit electromagnetic radiation, the block having a partially transmissive input face, an at least partially internally reflective output face and a pair of internally reflective side faces, such that said third proportion of electromagnetic radiation can, in use, partially externally reflect from and partially transmit through the input face, at least partially internally reflect from said output face, internally reflect from said side faces, and transmit back through the input face so as to interfere with the part that externally reflects from the input face.

The interferometric device preferably comprises the electromagnetic radiation splitter, wherein the interferometric device is arranged in the main electromagnetic radiation path for redirecting said first proportion of the electromagnetic radiation to the first electromagnetic radiation detector, for redirecting said second proportion of the electromagnetic radiation to the filter and for redirecting said third proportion of the electromagnetic radiation such that it interferes with itself and is directed to the third electromagnetic radiation detector.

The interferometric device is preferably formed of at least two conjoined sub-blocks of electromagnetic radiation transmitting material, so that the input and output faces of the interferometric device are formed from faces of the different sub-blocks, each sub-block having coatings of different reflective and transmissive characteristics formed thereon, whereby at least the input and output faces of the interferometric device have different reflective and transmissive characteristics on different areas thereof.

Preferably, at least one of the coatings provided on at least part of the output face of the interferometric device has a wavelength dependent transmission characteristic to form said filter.

The dimensions of the block are conveniently predetermined so that a portion of electromagnetic radiation incident on the input face of the block at an input area is internally reflected by the output face a predetermined number of times, so as to exit the block at the input area and interfere with the electromagnetic radiation incident on the input face of the block and externally reflected thereby, the predetermined number of times being determined according to the required spacing of interference peaks required at the third electromagnetic detector.

- 5
- 10 The predetermined number of times the electromagnetic radiation is internally reflected by the output face is preferably at least two times, and more preferably, at least three times.

In a further embodiment, the processing means compares the ratio of the first signal and the second signal with predetermined values to determine an approximate wavelength of the electromagnetic radiation, and compares the ratio of the first signal and the third signal with predetermined values to determine a more exact value for the wavelength of the electromagnetic radiation.

15

20

According to a second aspect, the invention provides a laser wavelength locking apparatus comprising a laser for emitting electromagnetic radiation along a main electromagnetic radiation path, an apparatus for detecting a wavelength of electromagnetic radiation emitted along said main electromagnetic radiation path as described above, a laser temperature controller coupled to the processing device for adjusting the temperature of the laser depending on the detected wavelength of the electromagnetic radiation emitted by the laser.

- 25
- 30 Preferably, the laser is a tunable laser.

In a third aspect, the invention provides a method of detecting a wavelength of electromagnetic radiation, the method comprising the steps of receiving a first proportion of electromagnetic radiation that has been redirected from a main electromagnetic radiation path, receiving a second
5 proportion of electromagnetic radiation that has been redirected from the main electromagnetic radiation path via a filter, receiving a third proportion of electromagnetic radiation that has been redirected from the main electromagnetic radiation path via an interferometric device so as to interfere with itself, processing a first signal indicating an intensity of the
10 first proportion of the electromagnetic radiation and a second signal indicating an intensity of the filtered second proportion of the electromagnetic radiation to provide a ratio of the first and second signals, processing the first signal and a third signal indicating an intensity of the interfered third proportion of the electromagnetic radiation to provide a
15 ratio of the first and third signals, and utilising the ratios of the first and second signals and the first and third signals to determine a wavelength of the electromagnetic radiation.

In a preferred embodiment, the method further comprises the step of
20 redirecting said first proportion of the electromagnetic radiation to a first electromagnetic radiation detector and of redirecting said second proportion of the electromagnetic radiation to the filter.

Preferably, the interferometric device comprises a block of material that
25 can transmit electromagnetic radiation, the block having a partially transmissive input face, an at least partially internally reflective output face and a pair of internally reflective side faces, the method comprising the step of redirecting said third proportion of electromagnetic radiation onto the input face of the block so that it is partially externally reflected from and
30 partially transmitted through the input face, at least partially internally reflected from said output face, internally reflected from said side faces,

and transmitted back through the input face so as to interfere with the part that is externally reflected from the input face.

In one preferred embodiment, the interferometric device is arranged in the main electromagnetic radiation path for redirecting said first proportion of the electromagnetic radiation to a first electromagnetic radiation detector, for redirecting said second proportion of the electromagnetic radiation to the filter and for redirecting said third proportion of the electromagnetic radiation such that it interferes with itself and is directed to a third electromagnetic radiation detector.

Preferably, the utilising step comprises comparing the ratio of the first signal and the second signal with predetermined values to determine an approximate wavelength of the electromagnetic radiation, and comparing the ratio of the first signal and the third signal with predetermined values to determine a more exact value for the wavelength of the electromagnetic radiation.

According to a fourth aspect, the invention provides a method of locking the wavelength of electromagnetic radiation emitted by a tunable laser, the method comprising the steps of emitting electromagnetic radiation from a tunable laser along a main electromagnetic radiation path, detecting a wavelength of electromagnetic radiation emitted along said main electromagnetic radiation path utilising the method described above, and adjusting a temperature of the laser depending on the detected wavelength of the electromagnetic radiation emitted by the laser.

In a fifth aspect, the invention provides an interferometric device comprising a block of material that can transmit electromagnetic radiation, the block having a partially transmissive input face, an at least partially internally reflective output face and a pair of internally reflective side faces, such that electromagnetic radiation incident on the input face, in use,

partially externally reflects from and partially transmits through the input face, at least partially internally reflects from said output face, internally reflects from said side faces, and transmits back through the input face so as to interfere with the part that externally reflects from the input face.

5

Preferably, the interferometric device is formed of at least two conjoined sub-blocks of electromagnetic radiation transmitting material, so that the input and output faces of the interferometric device are formed from faces of the different sub-blocks, each sub-block having coatings of different
10 reflective and transmissive characteristics formed thereon, whereby at least the input and output faces of the interferometric device have different reflective and transmissive characteristics on different areas thereof.

In one embodiment, the dimensions of the block are predetermined so that
15 a portion of electromagnetic radiation incident on the input face of the block at an input area is internally reflected by the output face a predetermined number of times, so as to exit the block at the input area and interfere with the electromagnetic radiation incident on the input face of the block and externally reflected thereby, the predetermined number of
20 times being determined according to the required spacing of interference peaks of the electromagnetic radiation.

Preferably, the predetermined number of times the electromagnetic radiation is internally reflected by the output face is at least two times, and
25 more preferably, at least three times.

According to a sixth aspect, the invention provides a method of causing electromagnetic radiation to interfere, the method comprising the steps of providing an interferometric device as described above, directing the
30 electromagnetic radiation onto the input face, so that it partially externally reflects from and partially transmits through the input face, at least partially internally reflects from said output face, internally reflects from said side

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faces, and transmits back through the input face so as to interfere with the part that externally reflects from the input face.

5 A seventh aspect of the invention provides a method of fabricating an interferometric device as described above, the method comprising the steps of conjoining at least two sub-blocks of electromagnetic radiation transmitting material, so that the input and output faces of the interferometric device are formed from faces of the different sub-blocks, each sub-block having coatings of different reflective and transmissive
10 characteristics formed thereon, whereby at least the input and output faces of the interferometric device have different reflective and transmissive characteristics on different areas thereof.

15 Preferably, the method further comprises the step of predetermining the dimensions of the block so that a portion of electromagnetic radiation incident on the input face of the block at an input area is internally reflected by the output face a predetermined number of times, so as to exit the block at the input area and interfere with the electromagnetic radiation incident on the input face of the block and externally reflected thereby, the
20 predetermined number of times being determined according to the required spacing of interference peaks of the electromagnetic radiation.

It should be appreciated that references to "light" herein refer to electromagnetic radiation of wavelengths between about 300 nm and
25 about 10 μm , preferably between about 400 nm and about 2 μm , very preferably between about 800nm and 1700nm.

Several embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings in which:-
30

FIG. 1 is a schematic diagram of a wavelength locking apparatus according to one embodiment of the present invention;

FIG. 2 is a schematic graph (including an enlarged portion in FIG. 2(b)) of light intensities in the apparatus of FIG. 1; and

FIG. 3 is a schematic diagram of a part of wavelength locking apparatus
5 according to a further embodiment of the present invention.

Throughout the following description identical reference numerals will be used to identify like parts.

10 Referring, first to FIG. 1, a first embodiment of a wavelength locking device is shown. In this embodiment, a tunable laser device 10, for example a semiconductor laser diode disposed in a laser package 12, is arranged to launch light emitted by the laser device 10 into an optical fibre 22. A collimating lens 11 is disposed adjacent the laser device 10. A reflective
15 component 13, in this example a bulk component having a first partially reflective surface 14 substantially opposite a second partially reflective surface 15, acts as a beam splitter and is disposed in a main optical path 16 adjacent the collimating lens 11. The first partially reflective surface 14 externally reflects a small proportion of the light incident on it from the collimating lens 11 and transmits the remainder, which is refracted at the
20 surface 14, through the component 13 to the second partially reflective surface 15. The second partially reflective surface 15 internally reflects a small proportion of the light incident on it from the first partially reflective surface 14 back to the first partially reflective surface 14 and transmits the
25 remainder, which is refracted at the surface 15, along the main optical path 16 towards the optical fibre 22.

To one side of the beam splitter 13, first and second photodiodes 17 and 18 are disposed. The beam splitter 13 is placed and aligned so as to
30 direct light, which was internally reflected from the second partially reflective surface 15 back to the first partially reflective surface 14 and partially transmitted (and refracted) through the first partially reflective

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surface 14, along a first optical path 19 towards the first photodiode 17. Similarly, the placing and alignment of the beam splitter 13 is such as to direct light reflected by the first partially reflective surface 14 along a second optical path 20 towards the second photodiode 18. An angle at which the beam splitter 13 is disposed relative to the main optical path 16 is one factor that can dictate the direction of the first and second optical paths 19, 20. Another factor is the relative position of the first partially reflective surface 14 and the second partially reflective surface 15 which can be varied so as to control respective reflection towards the first and second photodiodes 17, 18. A filter, for example a broadband filter, 21 is disposed in the second optical path 120 adjacent the second photodiode 18 so as to filter the light from the beam splitter 13 incident upon the second photodiode 18. The filter covers at least 30nm, preferably at least 40nm and most preferably 50 – 60 nm in waveband.

15 An interferometric device 23 is disposed in the main optical path 16 between the beam splitter 13 and the optical fibre 22. The interferometric device 23 is formed of a fused silica block having particular predetermined dimensions arranged to cause a proportion of light incident upon it to interfere so as to produce a wavelength dependent interference pattern of peaks and troughs. The device 23 has an input face 24 facing the main optical path 16 from the beam splitter 13 at an angle, and an output face 25 facing the main optical path 16 to the optical fibre 22. The input and output faces 24 and 25 are have a partially reflective coating provided over their areas where the main optical path 16 passed through them. Other parts of the input and output faces 24 and 25, as well as side faces 26 and 27, have a metallic reflective coating 28 disposed thereon to substantially internally totally reflect light incident on them, as will be further described below.

30 The interferometric device 23 is placed and aligned so as to direct a small proportion of light, reflected from the partially reflective coating on the input

face 24, along a third optical path 29 towards a third photodiode 30. The remainder of the light incident on the input face 24 is transmitted through the input face (and refracted) towards the output face 25, where, most of the light is transmitted through the output face (and refracted) into the

5 main optical path 16 outwards towards the optical fibre 22. However, a small proportion of the light incident on the output face 25 is internally reflected onto the side face 27, from where it is substantially totally reflected onto the part of the input face 24 that has the metallic reflective coating 28 disposed thereon, so that it is substantially totally internally

10 reflected therefrom to the part of the output face 25 that has the metallic reflective coating 28 disposed thereon, so that it is substantially totally internally reflected therefrom to the side face 26, from which it is substantially totally reflected back to the input face 24 at the point where it first entered the device. At this point, most of the light is transmitted

15 through the input face (and refracted) to interfere with the proportion of light that was initially reflected from the input face 24, and be directed into optical path 29 towards photodiode 30. Thus, the photodiode 30 receives an interference pattern caused by interference of the proportion of the light externally reflected from the input face 24 of the interferometric device 23

20 and the proportion of the light that passed into the interferometric device 23 and was then reflected internally to exit the interferometric device at the same point as it entered it.

In operation, therefore, light emitted by the laser diode 10 follows the main

25 optical path 16 and is collimated by the collimating lens 11 before propagating towards the beam splitter 13. Upon incidence upon the beam splitter 13, a proportion of the light emitted by the laser diode 10 is transmitted through first partially reflective surface 14 to the second partially reflective surface 15 of the beam splitter 23. A first proportion of

30 the light is reflected by the second partially reflective surface 15 and transmitted by the first partially reflective surface 14 towards the first photodiode 17 along the first optical path 19. A second proportion of the

light emitted by the laser diode 10 is reflected by the first partially reflective surface 14 towards the second photodiode 18 along the second optical path 20. Remaining, unreflected, light propagates through the beam splitter 23 so as to continue substantially along the main optical path 16
5 towards the interferometric device 23.

Upon incidence upon the interferometric device 23, a main proportion of the light from the beam splitter 13 is transmitted through input face 24 to the output face 25. A third proportion of the light is externally reflected by
10 the partially reflective coating on the input face 24 towards the third photodiode 30 along the third optical path 29. Of the light transmitted through the interferometric device 23 to the output face 25, a further proportion is internally reflected by the partially reflective coating on the output face 25 and is then substantially totally internally reflected around
15 all the faces of the interferometric device 23 until it reaches the input face 23 at the point at which the light entered the interferometric device 23. A proportion of that internally reflected light is then transmitted through the input face 23 and interferes with the light externally reflected by the input face 23 to produce an interference pattern at the third photodiode 30.
20 Remaining, unreflected, light propagates through the interferometric device 23 so as to continue substantially along the main optical path 16 towards the optical fibre 22.

Turning now to FIGs. 2(a) and 2(b), there is shown a schematic
25 representation of the amplitude (or intensity) of light incident on each of the three photodiodes 17, 18 and 30 as a function of wavelength. As can be seen in FIG. 2(a), the intensity of light incident on photodiode 17 (shown as graph Pd1) is substantially independent of wavelength and therefore provides a reference value for the intensity of light at a particular
30 wavelength. The intensity of light incident on the second photodiode 18, is shown as graph Pd2, and can be seen to be dependent on wavelength according to the transmission characteristic of the broadband filter 21.

Graph Pd3 shows the interference fringes formed by the interference of the light passing along the third optical path 29 to the third photodiode 30. FIG. 2(b) shows an enlarged portion of graphs Pd2 and Pd3 of FIG. 2(a).

- 5 From a consideration of the graphs shown in FIG. 2, it will thus be apparent that the ratio $Pd1/Pd2$ will not vary substantially over quite broad wavebands, so that the sole use of this ratio to determine the wavelength of the light will be prone to error and will not provide a very accurate mechanism for controlling the laser to maintain accurate wavelength output. On the other hand, the ratio $Pd1/Pd3$, although varying
- 10 substantially over narrow wavebands, will repeat periodically, according to the period of the peaks and troughs forming the interference fringes. Therefore, the latter ratio can be used to accurately maintain the wavelength of a laser, once it has been previously set, but cannot be used
- 15 to initially set the wavelength, since the ratio would be the same for a number of different wavelengths.

Accordingly, the outputs of photodiodes 17, 18 and 30 are passed to a processing device 31, such as a computer, to determine both ratios

20 $Pd1/Pd2$ and $Pd1/Pd3$. Using the first ratio $Pd1/Pd2$, the wavelength can be approximately determined using a look-up table. The second ratio $Pd1/Pd3$ can then be used to accurately determine the wavelength, again from a look-up table. Thus, the wavelength of the tunable laser device 10 can be initially set by the computer 31 by reference to pre-determined

25 tables stored in a memory. The second ratio can then be used to maintain the output of the laser at the desired wavelength if it begins to drift. The computer 31 therefore provides an output signal to a driver circuit (not shown) in the laser package 12, for example, a Proportional Integral Differential (PID) controller to influence the generation of light by the laser

30 diode 10 so as to ensure that the wavelength of the light generated by the laser diode 10 remains substantially at a required wavelength. Examples of influencing the generation of light by the laser diode 10 include

controlling the temperature of the laser diode 10, or where more than one current is applied to the laser diode 10, controlling one or more of those currents.

- 5 In another embodiment, and referring to FIG. 3, the apparatus of FIG. 1 is adapted by using the interferometric device to also provide the beam splitting and filtering functions. In this embodiment, light passes along the main optical path 6 from the laser device (not shown) through the collimating lens 11 directly to an interferometric device 32. The
- 10 interferometric device 32 is formed of two blocks 33 and 34 of fused silica conjoined to form a single block so that light passing between them is substantially unaffected. Prior to being joined together, the blocks 33 and 34 are coated with partially reflective coatings having different transmission characteristics on different faces. Thus, the input face 35 of
- 15 block 33 is provided with a coating that has 2% reflectiveness, whereas the output face 36 of block 34 has a coating with 8% reflectiveness. The side faces 37 and 38 have coatings of substantially 100% reflectiveness, as in the embodiment of FIG. 1, but face 39 of block 34 is provided with a coating having 50% reflectiveness, whereas face 40 of block 33 is
- 20 provided with a dichroic mirror coating, which also acts as a filter 41.

Thus, in operation, 2% of the light from the main optical path 16 incident on input face 35 is reflected along third optical path 42 towards the third photodiode 30, and 98% of the light is transmitted (and refracted) towards

25 the output face 36 of the device. 92% of the light incident on the output face 36 (that is 90% of the total light incident on the device) is transmitted along the main optical path 16 towards the optical fibre (not shown). However, 8% of the light incident on the output face 36 is internally reflected thereby and totally internally reflected off side face 37 to face 39.

30 In this embodiment, instead of totally reflecting the light, the 50% reflectiveness coating, reflects 50% of it and transmits 50% of it along the first optical path 43 to the first photodiode 17. Thus, approximately 4% of

the light originally incident on the device 32 is transmitted to the first photodiode 17. Of the remaining 50% reflected internally from face 39, a proportion is transmitted through face 40 and through dichroic filter coating 41 along the second optical path 44 to photodiode 18, and the rest is internally reflected off side face 38 to be transmitted through input face 35 to interfere with the portion of the light that was initially externally reflected from the input face 35, as described above in relation to FIG. 1. The outputs of the photodiodes are processed in the same manner as described earlier. As will be appreciated, this second embodiment is cheaper and easier to assemble, since it only has one component (the interferometric device) instead of three components (the beam splitter, the filter and the interferometric device).

In order to discriminate between different peaks and troughs in the interference pattern, the distance between adjacent peaks can be varied by adjusting the dimensions of the block(s) forming the interferometric device, in order to increase or decrease the number of times the light must travel backwards and forwards between the input and output faces. The more path lengths the light must travel, the lesser the spacing between the peaks in the interference pattern. Although, the two embodiments have been described as having substantially four path lengths between the input and output faces (including a path reflected off a side face as a single path length), it will be appreciated that other numbers of path lengths can be used, for example six path lengths or greater.

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Whilst only two particular embodiments of the invention have been described above, it will be appreciated that a person skilled in the art can make modifications and improvements without departing from the scope of the present invention. For example, when the interferometric device is used in the embodiment of FIG. 1, it may be possible to use other interferometric devices, such as etalons to provide the interference patterns, depending on the configuration of the beam splitter and the

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- photodiodes. Furthermore, although the reflective coatings have been stated as having particular values of reflectiveness, it will be appreciated that other values could be used. In particular, the reflectiveness of the coatings can be of any value that provides sufficient light for a clear
- 5 reading to be obtained by the respective photodetector, while balancing the need for most of the light to be transferred to the operating system.

Claims

1. An apparatus for detecting a wavelength of electromagnetic radiation, the apparatus comprising:
 - 5 a first electromagnetic radiation detector (17) for receiving a first proportion of electromagnetic radiation that has been redirected from a main electromagnetic radiation path;
 - a second electromagnetic radiation detector (18) for receiving a second proportion of electromagnetic radiation that has been redirected
 - 10 from the main electromagnetic radiation path;
 - a third electromagnetic radiation detector (30) for receiving a third proportion of electromagnetic radiation that has been redirected from the main electromagnetic radiation path;
 - a filter (21) arranged for filtering the second proportion of the
 - 15 electromagnetic radiation before it reaches the second electromagnetic radiation detector;
 - an interferometric device (23) arranged for causing the third proportion of the electromagnetic radiation to interfere with itself before it reaches the third electromagnetic radiation detector; and
 - 20 processing means (31) coupled to receive a first signal from the first electromagnetic radiation detector (17) indicating an intensity of the first proportion of the electromagnetic radiation detected by the first electromagnetic radiation detector (17), a second signal from the second electromagnetic radiation detector (18) indicating an intensity of the
 - 25 second proportion of the electromagnetic radiation from the filter (21) detected by the second electromagnetic radiation detector (18) and a third signal from the third electromagnetic radiation detector (30) indicating an intensity of the third proportion of the electromagnetic radiation from the interferometric device (23) detected by the third electromagnetic radiation
 - 30 detector (30), the processing means (31) determining a wavelength of the electromagnetic radiation based on the ratios of the first and second signals and the first and third signals.

2. An apparatus as claimed in claim 1, wherein said filter is a broadband filter.

5 3. An apparatus as claimed in either claim 1 or claim 2, further comprising at least one electromagnetic radiation splitter (13) arranged in the main path of the electromagnetic radiation for redirecting said first proportion of the electromagnetic radiation to the first electromagnetic radiation detector (17) and for redirecting said second proportion of the
10 electromagnetic radiation to the filter (21).

4. An apparatus as claimed in any one of the preceding claims, wherein said interferometric device (23) comprises a block of material that can transmit electromagnetic radiation, the block having a partially
15 transmissive input face (24), an at least partially internally reflective output face (25) and a pair of at least partially internally reflective side faces (26, 27), such that said third proportion of electromagnetic radiation can, in use, partially externally reflect from and partially transmit through the input face, at least partially internally reflect from said output face, at least
20 partially internally reflect from said side faces, and at least partially transmit back through the input face so as to interfere with the part that externally reflects from the input face.

5. An apparatus as claimed in claim 4, wherein said interferometric
25 device forms said electromagnetic radiation splitter, the interferometric device being arranged in the main electromagnetic radiation path for redirecting said first proportion of the electromagnetic radiation to the first electromagnetic radiation detector, for redirecting said second proportion of the electromagnetic radiation to the filter and for redirecting said third
30 proportion of the electromagnetic radiation such that it interferes with itself and is directed to the third electromagnetic radiation detector.

6. An apparatus as claimed in either claim 4 or claim 5, wherein said interferometric device is formed of at least two conjoined sub-blocks of electromagnetic radiation transmitting material, so that the input and output faces of the interferometric device are formed from faces of the different sub-blocks, each sub-block having coatings of different reflective and transmissive characteristics formed thereon, whereby at least the input and output faces of the interferometric device have different reflective and transmissive characteristics on different areas thereof.
7. An apparatus as claimed in claim 6, wherein at least one of said coatings provided on at least part of the output face of the interferometric device has a wavelength dependent transmission characteristic to form said filter.
8. An apparatus as claimed in any one of claims 4 to 7, wherein dimensions of the block are predetermined so that a portion of electromagnetic radiation incident on the input face of the block at an input area is internally reflected by the output face a predetermined number of times, so as to exit the block at the input area and interfere with the electromagnetic radiation incident on the input face of the block and externally reflected thereby, the predetermined number of times being determined according to the required spacing of interference peaks required at the third electromagnetic detector.
9. An apparatus as claimed in any one of the preceding claims, wherein said processing means compares the ratio of the first signal and the second signal with predetermined values to determine an approximate wavelength of the electromagnetic radiation, and compares the ratio of the first signal and the third signal with predetermined values to determine a more exact value for the wavelength of the electromagnetic radiation.

10. A laser wavelength locking apparatus comprising a laser for emitting electromagnetic radiation along a main electromagnetic radiation path, an apparatus for detecting a wavelength of electromagnetic radiation emitted along said main electromagnetic radiation path according to any
5 one of the preceding claims, a laser temperature controller coupled to the processing device for adjusting the temperature of the laser depending on the detected wavelength of the electromagnetic radiation emitted by the laser.

10 11. A method of detecting a wavelength of electromagnetic radiation, the method comprising the steps of:

receiving a first proportion of electromagnetic radiation that has been redirected from a main electromagnetic radiation path;

receiving a second proportion of electromagnetic radiation that has
15 been redirected from the main electromagnetic radiation path via a filter;

receiving a third proportion of electromagnetic radiation that has been redirected from the main electromagnetic radiation path via an interferometric device so as to interfere with itself;

processing a first signal indicating an intensity of the first proportion
20 of the electromagnetic radiation and a second signal indicating an intensity of the filtered second proportion of the electromagnetic radiation to provide a ratio of the first and second signals;

processing the first signal and a third signal indicating an intensity of the interfered third proportion of the electromagnetic radiation to provide
25 a ratio of the first and third signals; and

utilising the ratios of the first and second signals and the first and third signals to determine a wavelength of the electromagnetic radiation.

12. A method of detecting a wavelength of electromagnetic radiation
30 according to claim 11, further comprising the step of redirecting said first proportion of the electromagnetic radiation to a first electromagnetic

radiation detector and of redirecting said second proportion of the electromagnetic radiation to the filter.

13. A method of detecting a wavelength of electromagnetic radiation
5 according to either claim 11 or claim 12, wherein said interferometric device comprises a block of material that can transmit electromagnetic radiation, the block having a partially transmissive input face, an at least partially internally reflective output face and a pair of internally reflective side faces, the method comprising the step of redirecting said third
10 proportion of electromagnetic radiation onto the input face of the block so that it is partially externally reflected from and partially transmitted through the input face, at least partially internally reflected from said output face, internally reflected from said side faces, and transmitted back through the input face so as to interfere with the part that is externally reflected from
15 the input face.

14. A method of detecting a wavelength of electromagnetic radiation according to any one of claims 11 to 13, wherein said utilising step comprises comparing the ratio of the first signal and the second signal with
20 predetermined values to determine an approximate wavelength of the electromagnetic radiation, and comparing the ratio of the first signal and the third signal with predetermined values to determine a more exact value for the wavelength of the electromagnetic radiation.

25 15. A method of locking the wavelength of electromagnetic radiation emitted by a tunable laser, the method comprising the steps of:

emitting electromagnetic radiation from a tunable laser along a main electromagnetic radiation path;

30 detecting a wavelength of electromagnetic radiation emitted along said main electromagnetic radiation path utilising the method of any one of claims 11 to 14; and

adjusting a temperature of the laser depending on the detected wavelength of the electromagnetic radiation emitted by the laser.

16. An interferometric device (32) comprising a block of material that
5 can transmit electromagnetic radiation, the block having a partially transmissive input face (35), an at least partially internally reflective output face (36) and a pair of at least partially internally reflective side faces (37, 38), such that electromagnetic radiation incident on the input face (35), in use, partially externally reflects from and partially transmits through the
10 input face (35), at least partially internally reflects from said output face (36), at least partially internally reflects from said side faces (37, 38), and at least partially transmits back through the input face (35) so as to interfere with the part that externally reflects from the input face (35).

17. An interferometric device as claimed in claim 16, which is formed of
at least two conjoined sub-blocks (33, 34) of electromagnetic radiation
transmitting material, so that the input (35) and output (36) faces of the
interferometric device are formed from faces of the different sub-blocks
(33, 34), each sub-block having coatings of different reflective and
20 transmissive characteristics formed thereon, whereby at least the input and output faces of the interferometric device have different reflective and transmissive characteristics on different areas thereof.

18. An interferometric device as claimed in either claim 16 or claim 17,
25 wherein dimensions of the block are predetermined so that a portion of electromagnetic radiation incident on the input face of the block at an input area is internally reflected by the output face a predetermined number of times, so as to exit the block at the input area and interfere with the electromagnetic radiation incident on the input face of the block and
30 externally reflected thereby, the predetermined number of times being determined according to the required spacing of interference peaks of the electromagnetic radiation.

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19. A method of causing electromagnetic radiation to interfere, the method comprising the steps of:

5 providing an interferometric device according to any one of claims 16 to 18;

10 directing the electromagnetic radiation onto the input face, so that it partially externally reflects from and partially transmits through the input face, at least partially internally reflects from said output face, internally reflects from said side faces, and transmits back through the input face so as to interfere with the part that externally reflects from the input face.

20. A method of fabricating an interferometric device of any one of claims 16 to 18, the method comprising the steps of:

15 conjoining at least two sub-blocks of electromagnetic radiation transmitting material, so that the input and output faces of the interferometric device are formed from faces of the different sub-blocks, each sub-block having coatings of different reflective and transmissive characteristics formed thereon, whereby at least the input and output faces of the interferometric device have different reflective and transmissive
20 characteristics on different areas thereof.

4

ABSTRACT

WAVELENGTH DETERMINING APPARATUS AND METHOD

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An apparatus for determining the wavelength of light emitted by, for example, a laser (10), includes three photodiodes (17, 18, 30). One photodiode (17) receives a proportion of the light redirected from the main optical path (16) by a beam splitter (13). A second photodiode (18) receives a proportion of the light redirected from the main optical path (16) by the beam splitter (13) and passing through a broadband filter (21). A third photodiode (30) receives light that has been caused to interfere by an interferometric device (23). The interferometric device (23) is formed of a block having partially reflective surfaces so that part of the light is reflected internally within the block and exits at the same place as it entered so as to interfere with light that was externally reflected by the block at that place. The ratio of the light intensities at the first and second photodiodes provide a coarse determination of wavelength, when compared to a look-up table, and the ratio of the light intensities at the first and third photodiodes provide a more exact determination of the wavelength.

(FIG. 1)

(1/2)

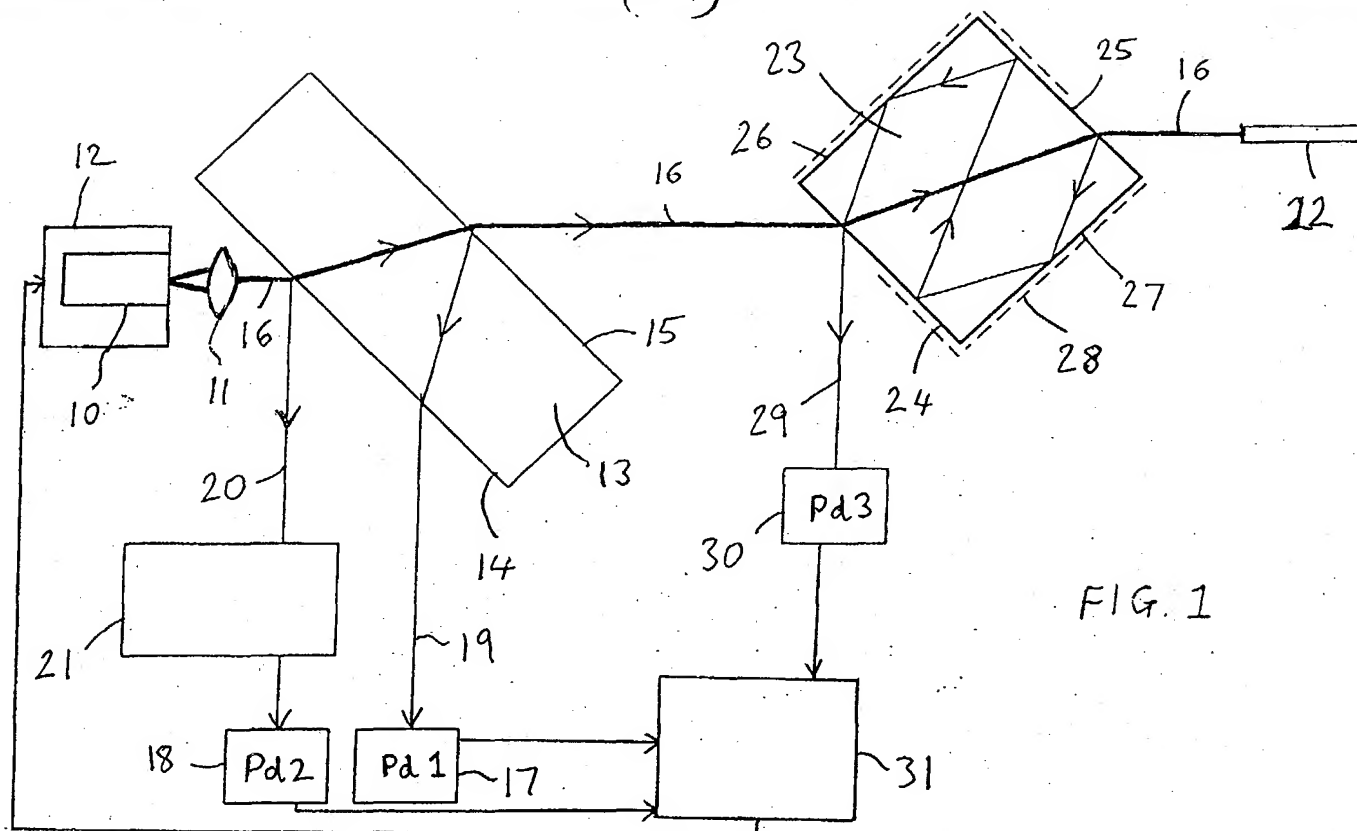


FIG. 1

Amplitude

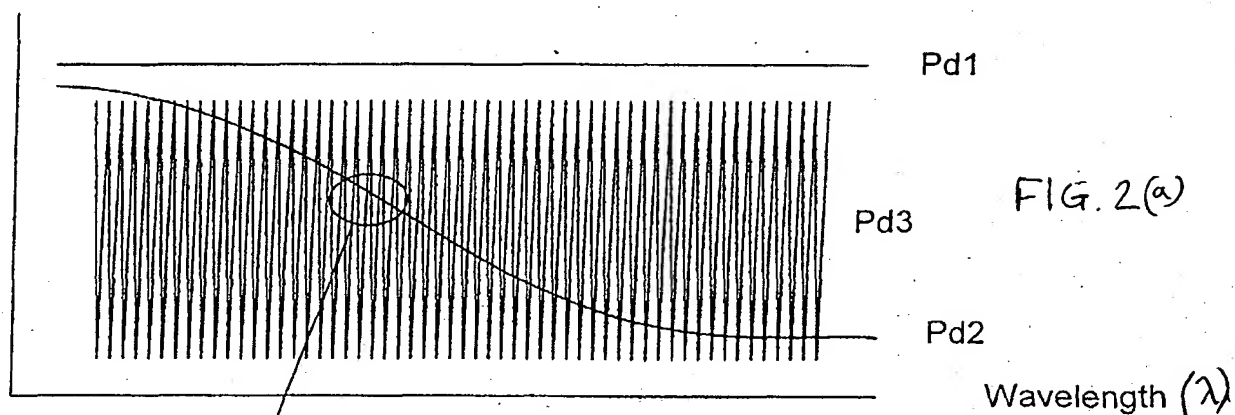


FIG. 2(a)

Amplitude

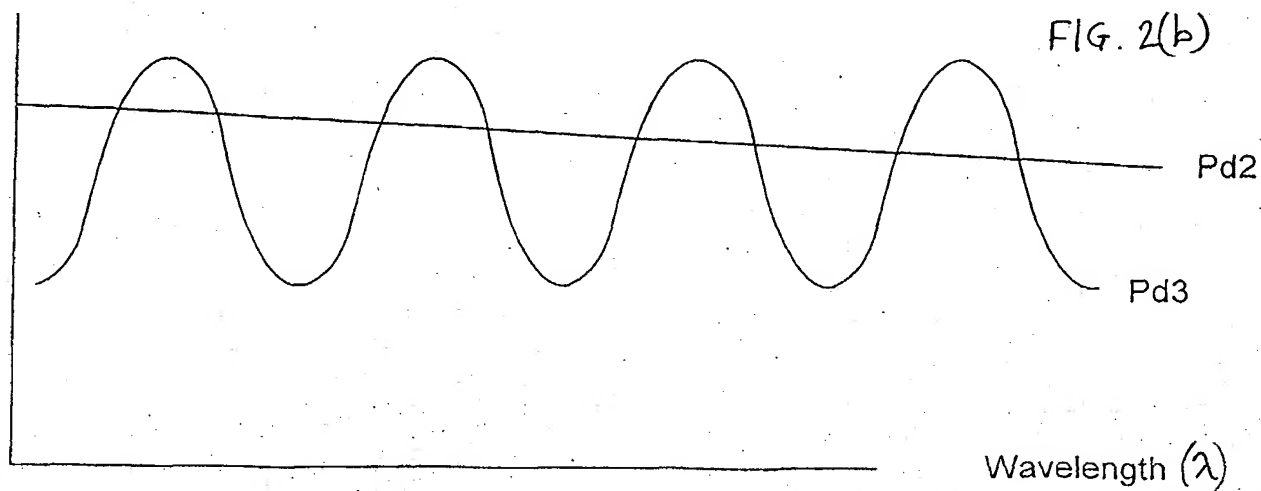


FIG. 2(b)

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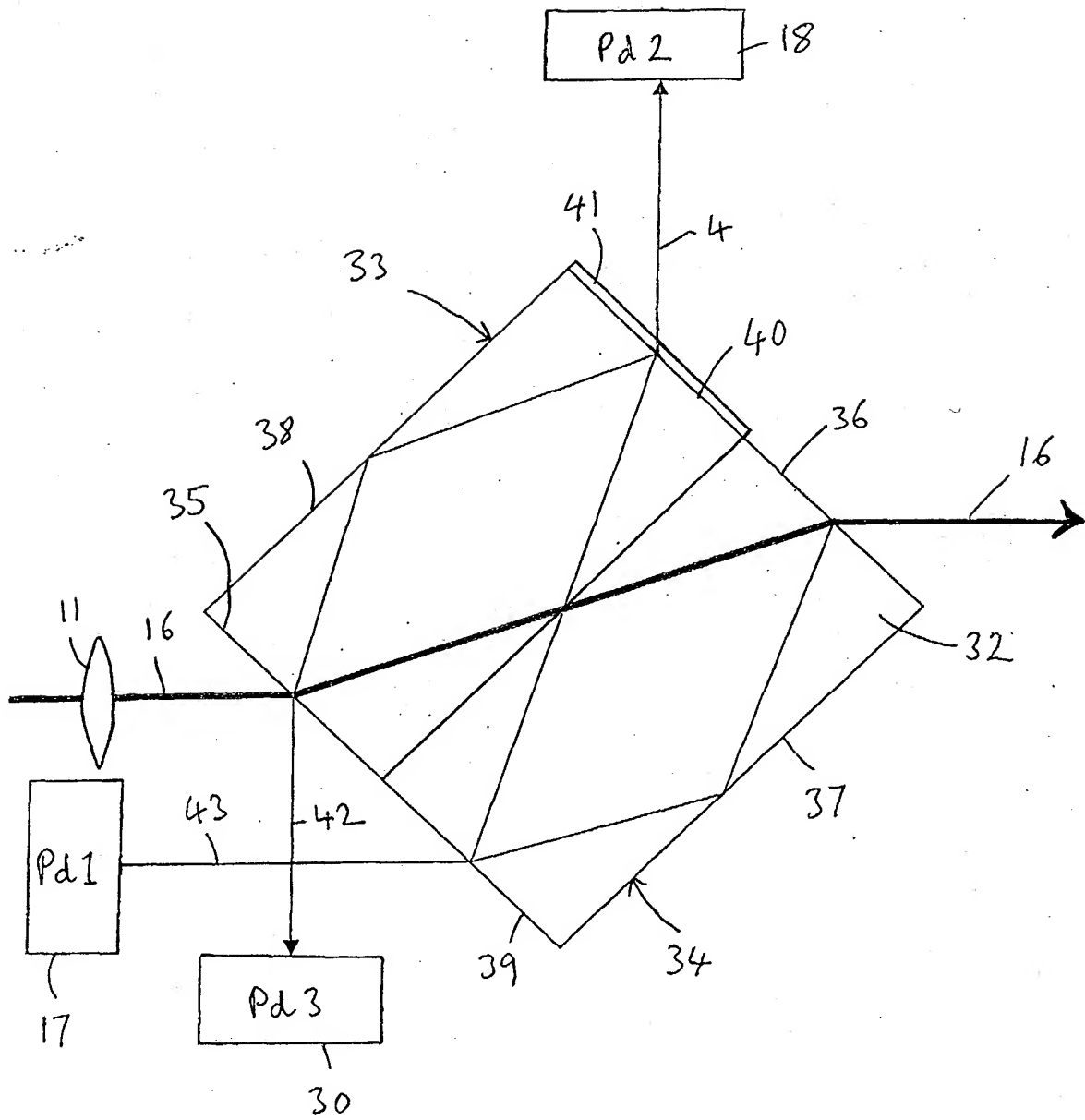


FIG. 3